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AN ECONOMY WIDE ENERGY MODEL
FOR EGYPT

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No. 530 July 1989

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I. INTRODUCTION

This paper describes a model for the Egyptian economy that can be used in analyzing energy and other economic policy issues in the context of structural adjustment programs. The main features of the model are that it is economy-wide, multisectoral, dynamic, long-run, and obeys rules of economic efficiency, subject to exogenous constraints.[1] The model projects the future levels of economic activity and energy supply and demand at regular intervals over a 25-year time horizon. By disaggregating the economy the model is able to investigate the important interactions of structural change with energy demand at a finer level of detail than in a fully aggregated model.[2]

The endogenous variables of the model include the time paths of domestic production, consumption demand, investment and, foreign trade. Each of these projections is made at the sectoral level. The algebraic constraints imposed on the model insure that the endogenous variables are always internally consistent and feasible. Feasibility is defined in terms of domestic and foreign resource constraints, including capital stocks and labor supply, available technology, crude oil reserves, foreign ex-

1The model is a lineal descendant of the optimizing models reviewed in Taylor (1975).
2The number and choice of sectors was determined on the basis of data availability and the desire to have as much detail on the energy sectors as possible.

change reserves and foreign borrowing opportunities, and the structure of world prices.

Model solutions are obtained using an optimizing algorithm where the objective is to maximize economic welfare during the planning horizon. The results are equivalent to solving for a general equilibrium in which consumers behave according to their demand functions, that are sensitive to income and prices, and in which producers competitively act to maximize profits. In this sense, the model is meant to simulate economic behavior and not just reflect the planners' objectives.

A model with this structure is well-suited for addressing a number of key issues facing the Egyptian economy. These include:

--the composition and rate of expansion of domestic energy demand, its sensitivity to domestic prices and the changing structure of the economy;

--the impact on the Egyptian economy of changes in oil export revenue due to changes in the world price of oil;

--the effects on oil exports, overall economic performance and the pattern of energy demand of programs to increase domestic use of natural gas;

--the capacity expansion requirements in the various energy sectors of different rates and patterns of growth and the potential contribution of cogeneration and improved efficiency in reducing total costs;

--the adjustment of the economy to diminishing foreign borrowing opportunities.

These types of issues can be studied by comparing the model's solution for different "scenarios" incorporating different assumptions about exogenous factors and different policy measures. These include external conditions, such as foreign borrowing limits and world prices for traded goods, and new discoveries of hydrocarbon reserves. Alternative assumptions about the domestic economy and policy can also be investigated as, for example, the range of technological alternatives available to each sector and the effects of consumption taxes or subsidies and various restrictions on international trade.

II. MODEL DESCRIPTION AND ALGEBRAIC FORMULATION

The Egyptian economy is divided into ten sectors, each covering a different collection of goods and services. These include six non-energy sectors: agricultural goods, manufactured goods, construction, transportation, other services, and non-competing imports. There are four energy sectors: crude oil, natural gas, petroleum products, and electricity. Table 1 contains a full listing of the endogenous variables and Table 2 defines all parameters and exogenous variables. The endogenous variables include production and investment growth in each sector, the pattern of private or household consumption, energy demand and supply, foreign trade, and relative prices. The variables are calculated for five evenly-spaced years 1992, 1997, 2002, 1007, and 2012.

The accounting identities for each sector and pe

riod are consistent with rules for national income accounting. These supply-demand balances for goods and services, sometimes called "material balances," are contained in equations (1).

$$X_{i,t} + M_{i,t} = Z_{i,t} + C_{i,t} + \overline{G}_{i,t} + I_{i,t} + E_{i,t} \tag{1}$$

The left side of (1) is the total supply of good i in year t, and it consists of domestic production $X_{i,t}$ and competitive imports, $M_{i,t}$. The right side of equation (1) includes all categories of demand and usage. These are intermediate uses in production, deliveries to private and public consumption, investment demand, and exports. For many sectors, including the energy sectors, the intermediate uses are the largest component of demand. When "i" refers to non-competing imports, domestic production is zero and all supply is imported.

The model recognizes that, in general, the same good or services can be produced in a variety of ways by "alternative" technologies with different cost and input patterns. Total production in a sector is the sum of the production by each technology, k. That is:

$$X_{i,t} = \sum_{k} X_{i,k,t} \tag{2}$$

Equation (3) shows total intermediate or interindustry demand for good i as the sum of deliveries for each technology in each producing sector in the economy.

$$Z_{i,t} = \sum_{j} \sum_{k} a_{i,j,k} X_{j,k,t} \tag{3}$$

The requirement for foreign exchange balance is that the supply of foreign exchange from all sources be equal to the sum of all uses. Four sources of foreign exchange are distinguished: export earnings, workers' remittances, net foreign borrowing, and other transfers. Exports and borrowing are endogenous variables (subject to limits), while workers' remittances and transfers are projected exogenously. Interest rates are exogenous, but the level of debt is (partially) endogenous The right side of equation (4) contains the three uses of foreign exchange: purchase of imports, interest payments on foreign debt, and remittances of foreign companies doing business in Egypt (mainly oil companies).

Foreign trade activities are measured in foreign exchange, millions of current U.S. Dollars. The prices for each export and import, $E_{i,t}$ and $M_{i,t}$, are U.S. Dollars per 1987 Egyptian Pounds. Export and import prices for the same good differ because of the trade and transport margins added to import prices.

For each year, t, equation (4) must hold.

$$\sum_{i} P^{e}_{i,t} E_{i,t} + \overline{W}_t + \overline{T}_t + B_t = \sum_{i} P^{m}_{i,t} M_{i,t} + i_t D_t + \overline{V}_t \tag{4}$$

The unit demands for intermediate inputs of good and services are summarized in the $a_{i,j,k}$ parameters, where this amount

of good i is required to produce one unit of good j using technology k. With one exception these parameters are exogenous. The model takes the unit demand for fuels as fixed for each technology, but this demand can be met by using either natural gas or petroleum products. This relationship is shown in equation (5). At the same time, there are limits placed on the degree to which natural gas and petroleum products can substitute for each other. These limits, summarized in the inequality constraints (6), are specific for each technology.

$$a_{gas,j,k} + a_{pet,j,k} = a_{fuel,j,k} \tag{5}$$

$$a_{gas,j,k} \leq s_{j,k}\, a_{fuel,j,k} \tag{6}$$

One potential constraint on production is labor supply. The model calculates the economy-wide demand for labor as the sum over all producing sectors and technologies of production times unit demands for manpower, $l_{i,k}$. This cannot be greater than the exogenously specified labor supply, L_t.

$$\sum_i \sum_k l_{i,k} X_{i,k,t} \leq \bar{L}_t \tag{7}$$

An additional constraint is placed on the demand for agricultural labor. Reflecting the imperfect mobility between the urban and rural sectors, and increasing tightness of the rural

labor markets in the past decade, agricultural employment is limited by a forecast of the rural employment pool.

$$\sum_{k} l_{agr,k} X_{agr,k,t} \leq \bar{L}_{agr,t} \tag{8}$$

While the labor constraints operate across technologies and sectors, capital constraints are more specific. That is, yearly production using any technology is limited by the amount of productive capacity or installed capital, $K_{i,k,t}$, available in that year. Once installed, capital is not fungible to other sectors or technologies. Initial, 1987, capacity in each sector is given as data.

$$X_{i,k,t} \leq K_{i,k,t} \tag{9}$$

Finally, production of hydrocarbons is constrained by resource availability. It is well-known that there are technical limits to how rapidly producing fields can be depleted. In the model, these are summarized in constraints (10) which limit production in a year to no more than a certain percent of proven reserves in that year. Here, the subscript i refers to the crude oil and natural gas sectors. The parameter "q" in these constraints converts production in millions of 1987 Egyptian Pounds into reserve units (millions of barrels or billions of cubic feet).

$$q_l X_{l,t} \leq a_l R_{l,t} \tag{10}$$

The constraints on foreign borrowing in the model are crucial ones. These constraints (11), place upper bounds on the amount of net foreign borrowing that can take place in each year.

$$B_t \leq \overline{B}_t \tag{11}$$

Together with the other items in balance of payments identity, equation (4), the constraints in (11) limit the size of the annual trade deficits and, hence, the ability of the economy to import and to augment domestic savings with foreign savings.

Foreign trade occurs in: agriculture, manufacturing, transportation, other services, crude oil, and petroleum products. In these sectors any differences between domestic demand and domestic supply are made up by international trade. However, there are real world limitations on how rapidly import substitution and export promotion can occur. The model recognizes these and constrains the rate of change in imports and exports as follows.

$$M_{l,t} \geq (1-m_l) M_{l,t-1} \tag{12}$$

$$E_{l,t} \leq (1+e_l) E_{l,t-1} \tag{13}$$

The future values of some of the most important variables are determined by actions that are prior in time. Investment, foreign borrowing, and extraction today determine how much productive capacity, foreign debt, and hydrocarbon reserves there will be tomorrow. Equations which relate activity levels in one year with stock changes between periods are dynamic linkages that play a crucial role in the model. In these dynamic relations, the years t and t+1 are five years apart. Since the quantities in each period are yearly averages, the equations include appropriate interpolations between periods.

The most important dynamic equations involve investment and production capacity. Expanding future capacity requires investment activity in previous years due to gestation lags. Since the capacity, once installed, is no longer fungible, investment activity must be specified by sector and technology of destination. Installed capacity to produce good i using technology k in year t+1, $K_{i,k,t+1}$, is the sum of the level of capacity which already exists in year t, less depreciation, plus an amount related to the annual rate of new capacity which first becomes available in year t+1, $\Delta K_{i,k,t+1}$.

$$K_{i,k,t+1} = K_{i,k,t}\left(1-d_{i,k}\right) + f_{i,k}\,\Delta K_{i,k,t} \tag{14}$$

The parameter $f_{i,k}$ interpolates the annual rate $\Delta K_{i,k,t+1}$ into a 5-year total increase in new capacity. The shorter the gestation lag of the technology, the larger will be the parame-

ter. When the depreciation rate is large, $f_{i,k}$ will be smaller. Note that while the new capacity is first used in year t+1, the capital expenditures actually occur in prior years.

Over time, extraction of crude oil depletes and discoveries augment reserves. The extraction rates are endogenous variables, while discoveries are predetermined. That is, crude oil and natural gas reserves in year t+1 are the sum of the level of reserves in year t, plus exogenous discoveries made between year t and t+1, $\overline{\Delta R}_{i,t+1}$, less five times the average level of extraction between year t and year t+1, which is $(X_{i,t+1} + X_{i,t})/2$.

$$R_{i,t+1} = R_{i,t} + \overline{\Delta R}_{i,t+1} - 2.5(X_{i,t+1} + X_{i,t})q_i \tag{15}$$

Finally, the level or foreign debt in year t+1 is defined as the level in year t plus five times the average level during the period between years t and t+1, or $(B_{t+1} + B_t)/2$.

$$D_{t+1} = D_t + 2.5(B_{t+1} + B_t) \tag{16}$$

It has already been emphasized that there is a time lag between when investments are made and when they become operational and are added to productive capacity. The most important investment goods are construction, non-competing imports of equipment, and manufactured machinery. Equation (17) shows that demand for investment goods, by sector of origin, is the sum of specific demands by sector and technology of destination. Investment

demand at this level, $I_{i,j,k,t}$, is determined by the capital requirements profile for each technology and by the amount of new capacity creation to take place, $\Delta K_{j,k,t+1}$.

$$I_{i,t} = \sum_j \sum_k I_{i,j,k,t} \tag{17}$$

$$I_{i,j,k,t} = b_{i,j,k}\, ICOR_{j,k}\, \Delta K_{j,k,t+1} \tag{18}$$

In equation (18), the parameter $ICOR_{j,k}$ is an incremental capital-output ratio which relates a unit increase in capacity (specific by sector and technology) to a demand for capital goods. The parameters $b_{i,j,k}$ subdivide total demand for capital into proportions required of specific (by sector of origin) types of capital goods. By definition, these proportions sum to unity.

There are special constraints limiting investment levels initially and for the terminal year. The first year in which production capacity is endogenous is 1992. But capacity that year depends on the level and pattern of investment which occurs between the base year, 1987,and 1992. In (19) the model limits capacity creation in 1992 to a pattern which is consistent with the actual level of aggregate investment in 1987.

$$\sum_i I_{i,1987} \leq \bar{I}_{1987} \tag{19}$$

There is the opposite problem in the case of investment demand in the terminal year, 2012. Since these activities create

productive capacity only after the end of the model's horizon, they have no intrinsic value within the 25-year planning period. Unless otherwise restricted, the model will automatically minimize investment in the terminal year. Constraints (20) are introduced to compensate for the required finite time horizon. These stipulate that investment in the terminal year must be sufficient for domestic production, within each sector, to grow at a specified rate, g_i in the first period after the 2012.

$$\sum_k K_{i,k,2017} \geq (1+\bar{g}_i) \sum_k K_{i,k,2012} \tag{20}$$

The entire set of constraints for the model is contained in equations (1) to (20). Together they determine the time paths of the endogenous variables that are feasible for a given set of parameters and exogenous variables. The model chooses the feasible solution which maximizes economic welfare during the entire planning horizon.

The specific objective function used by model is defined in equation (21). Here, the term $U(C_t)$ represents the utility to the average consumer of the per capita consumption bundle, $C_{i,t}/N_t$, in year t. To obtain total consumer utility for year t, per capita utility is simply multiplied by the population in that year, N_t. Finally, utility in future years is discounted to the present at the fixed rate, ρ.

$$W = \sum_t \left(\frac{1}{1+\rho}\right)^t N_t \, U(C_t) \tag{21}$$

Yearly per capita utility levels, $U(C_t)$, are calculated in equation (22). The contribution of each specific consumer good "i" is measured as the product of the parameter B_i times the natural logarithm of the difference between per capita consumption of that good, $C_{i,t}/N_t$, and the fixed parameter i.

$$U(C_t) = \sum_i \beta_i l_n \left(\frac{C_{i,t}}{N_t} - \gamma_i \right) \tag{22}$$

The solution to the model is found by maximizing the variable W, subject to the restrictions imposed by constraints (1) to (22). The GAMS/MINOS system is used to solve the problem.[3]

In addition to calculating optimal values for the "primal" variables contained in equations (1) to (22), the model also determines a set of "dual" variables, or "shadow prices." Technically, a shadow price is the amount by which the objective function would increase if some constraint were relaxed by a small amount. The number of shadow prices, therefore, is the same as the number of constraints. These endogenous shadow price variables are important results because of their economic interpretation and policy implications.

The shadow prices can be thought of as indicating opportunity costs and therefore as an "efficiency" price. For example, the cost (in terms of foregone welfare) of producing or

[3] General Algebraic Modeling System (GAMS) uses a program called MINOS to solve nonlinear problems.

consuming one unit of good i in year t would be the shadow price associated with the accounting balances (1); the cost of labor would be the shadow price associated with constraint (7); the annualized capital costs of each type of production capacity would be the shadow price associated with constraints (9); and the economy-wide cost of foreign exchange would be the shadow price associated with constraint (11). Similar interpretations can be put on all the other shadow prices as well.

The information contained in the solution's shadow prices are a projection of the changes in efficiency prices during the model's horizon. From a planning perspective, the shadow prices are, therefore, useful for project evaluation. Market prices in Egypt, as in many developing countries, are often distorted, in the sense that do not accurately reflect relative opportunity costs. This means that valuing a project at market prices will not give an accurate indication of its economic present value. Using shadow prices where market prices are distorted will provide a better indicator of a project's net value to society.

An important illustration of the quantity/price duality is the case of consumer behavior. If we assume that the average consumer each year tries to maximize utility, $U(C_t)$, as given in equation (22) subject to a constraint on total spending, C_t, and facing the shadow prices, $P_{i,t}$, it follows that consumer spending behavior would be fully characterized by a linear expenditure system of demand functions. Equations (23) state that per capita spending on good i in year t is the sum of the price of that good

i, $P_{i,t}$, times the constant term, g_i, plus a fixed proportion, b_i, of the difference between C_t and the variable g_t. Definitions of these terms is contained in equations (24) and (25).

$$P_{i,t}\,C_{i,t} = \overline{N}_t\left(P_{i,t}\,\gamma_i + \beta_i\left(C_t - \gamma_t\right)\right) \tag{23}$$

$$C_t = \frac{\sum_i P_{i,t}\,C_{i,t}}{\overline{N}_t} \tag{24}$$

$$\gamma_t = \sum_i P_{i,t}\,\gamma_i \tag{25}$$

In effect, consumer spending depends on the model's determination of prices and per capita consumption spending in each year. The model chooses the optimal time path taking into account the tradeoffs between near term and long term per capita consumption.

Similarly, it can be shown that the model's solution is equivalent to competitive, profit maximizing behavior by firms.

III. DATA BASE AND PARAMETERIZATION

Numerical implementation of the model requires an extensive set of estimated parameters and exogenous projections (summarized in Table 2). The data needs can be classified into four broad categories: technological relationships, behavioral relationships, miscellaneous exogenous or predetermined variables, and initial conditions.

Much of the data necessary for the implementation of the model is taken from the estimated transactions matrix (Table 3).[4]

Construction of the 1986/87 transactions table involved, first, aggregating the 37-sector CAPMAS matrix into the ten-good classification used by the model and then making it consistent in terms of physical quantity balances for 1983/84. The final step was updating to the base year of 1986/87.[5]

In order to make it possible for the solutions to embody inter factor substitutions, it was necessary to specify a set of technological alternatives in each sector. The first of the alternative production technologies embodied in the input-output coefficients was calculated as the ratio of intermediate purchases by sector i of good j to the level of gross output of sector i in 1986/87. The other alternative technologies allow for substitution between fuels, electricity, labor, and capital with the other intermediate technological coefficients remaining unchanged. The alternative technologies were derived using a small program based on estimates of: i) the initial technology, ii) the own-price elasticity of energy for the sector; and iii) the sectoral elasticities of substitution between labor and capital, be-

4 The primary sources of this table were a recently completed thirty-seven sector transactions table for 1983/84 prepared by Central Agency for Public Mobilization and Statistics (CAPMAS); the import flow matrices underlying the CAPMAS transactions table, both inclusive and exclusive of paid tariffs;statistical reports of the Organization for Energy Planning (OEP), the the Egyptian General Petroleum Corporation (EGPC), the Egyptian Electricity Authority (EEA), the Central Bank of Egypt and the World Bank.

5The methodology followed in this process is described in a paper available on request from the authors.

tween labor and energy, between capital and energy, and between electricity and fuels. These were drawn from various sources.

The parameters of the linear expenditure system embodied in equations (23) - (25) were first estimated econometrically and then adjusted for consistency with the model's base year. Since these equations are highly interrelated, a complete systems approach was used to econometrically estimate the parameters.[6]

The population of Egypt in 1986/87 was 50.2 million people. Future population levels, N_t, are calculated assuming an annual growth rate of 2.5 percent. The initial year labor coefficients discussed earlier were based on this data. The total labor force is projected to grow by 3 percent a year over the entire planning horizon, starting from an initial level of 12.2 million. The labor force grows faster than the total population to reflect the relatively young population and increased labor force participation. An upper bound was placed on agricultural labor supply, $L_{agr,t}$, to reflect tightness in that labor market. The projected rate of growth of agricultural labor supply is one-half the economy-wide rate, or 1.5 percent annually.

Base year energy reserves of crude oil and natural gas were estimated at 4.5 billions of barrels and 8.89 billion cubic feet respectively.

Net foreign borrowing is projected to be the rate of net borrowing in 1986/87 ($3.76 billion) increased at the world in-

6 The approach of Pollak and Wales (1978) was used to estimate the parameters econometrically. The database for estimating these parameters was constructed by pooling cross-section family budget data which was available for two time periods, 1974/75 and 1980/81.

flation rate of 4 percent per year. The nominal interest rate on foreign debt is taken to be 6 percent annually over the entire planning horizon. The initial level of foreign debt was estimated to be $45 billion.

IV. ILLUSTRATIVE RESULTS

A Base Case was constructed to provide a reasonable and consistent benchmark solution for comparison in testing of model's sensitivity to changes in exogenous parameters and policies. The exogenous projections for the Base Case are summarized as follows:

-- World oil prices remain at 1986/87 levels in real terms throughout the planning horizon (about $14 per barrel), with nominal prices (in Dollars) increasing at the assumed world inflation rate of 4 percent per year.

-- The rate of discovery of new oil and natural gas reserves in Egypt is constant during the planning period, at 150 million barrels of oil and 700 billion cubic feet of natural gas annually.

-- Substantial substitution of natural gas for petroleum products can occur in electricity generation, refining, and industry. It is assumed that natural gas can, in principle, provide 100 percent of the fuel required for new electricity generation and 80 percent of the requirements for existing fossil fuel plants, one-half of the fuel required by the refinery sector, and two-thirds of manufacturing's fuel demand.

-- To reflect the difficulties of entering foreign markets and diverting sales to exports, the upper bounds on the rates of

growth of manufactured and agricultural exports (in quantity terms) are set at 9 percent and 2 percent per year respectively. The yearly real growth rates for transportation and services (tourism) exports are 2 percent and 4 percent.

-- For the balance of payments, the levels of net foreign borrowing, workers' remittances, other transfers, and foreign profit remittances all are made to grow at the world inflation rate of 4 percent annually.

-- Government consumption increases at 2.5 percent annually, maintaining constant per capita levels.[7]

The accompanying tables present actual levels for each variable in the base year (1987) and the levels generated in the Base Case solution in the first three endogenous periods (1992, 1997, and 2002). Results are presented only up to 2002. Because of inevitably imperfect terminal conditions, the investment pattern and results for the last periods of models such as this are not precise enough to be reliable.

The projected macroeconomic variables are presented in Table 4. These are "real" variables, in the sense that all quantities are shown in millions of 1986/87 Egyptian Pounds. Aggregate GDP

7 However, we specifically do not claim that this particular scenario is our best estimate of future developments. There are several reasons for this. First, there is the question of the accuracy and up-to-dateness of the parameters and constraints embodied in the model. Secondly, the projections are the result of an optimizing model simulating a dynamic general equilibrium that is efficient in all decisions, including the setting of prices. By comparison investment, pricing, trade, and production decisions in Egypt, as in other countries, are not always made on the basis of complete economic efficiency. The Base Case is discussed in detail to illustrate the full range of results the model produces.

growth averages 3.5 percent annually over the 15-year period, 1987-2002. Because the real trade deficit is falling at 7.1 percent per year, domestic absorption of goods, the sum of private consumption, government consumption, and gross investment, grows more slowly than GDP, at an average rate of 3.1 percent.

There is an interesting time pattern of the investment and private consumption paths projected by the model. In the first period, between 1987 and 1992, private consumption is held down to annual growth rate of 1.8 percent while investment grows at 6.5 percent annually. The model chooses to limit consumption growth and increases near-term domestic savings and investment in order to maximize the capacity of the economy to achieve higher long-term productivity and growth. Subsequently, private consumption is projected to grow somewhat faster than investment. Note that this tendency to postpone consumption occurs in spite of the fact that the intertemporal utility function being maximized is strongly non-linear.

The growth in public consumption is exogenously specified and, thus, reflects the assumption of a constant 2.5 percent annual growth.

The severe limits on foreign borrowing and the balance of payments, which are assumed in the Base Case, require a reduction in the trade deficit, which in Table 4 is measured in "real" terms, or in constant 1987 domestic prices. That increases the relative scarcity of foreign exchange as indicated by the rising price of foreign exchange and, as well, the higher prices of

those goods that use foreign exchange intensively. The reason that the shadow price of foreign exchange increases at a slower rate than the price of non-competing imports merely reflects the assumed 4 percent annual rate of world inflation.

The reactions on the real side include increased substitution of gas for petroleum products, expansion of exports and reduction of imports. In fact export growth is constrained at the exogenously specified limits for manufacturing, agriculture, tourism and services and Suez Canal and other transportation sector revenues.

Crude oil exports fall, however, due to the slow decline in oil reserves. If larger discoveries were made, the model would choose to exploit them and increase oil exports. Exports of refined products are eliminated because those are calculated not to be cost-effective. In general, in the Base Case solution it is in Egypt's interest for non-energy exports to take the place of energy exports due to the growth of energy demands and the decline in oil reserves. During the 1990's crude oil loses its position as the most important export sector, and is replaced by manufacturing. By 2002, both transportation and services are projected to earn more foreign exchange than the oil sector. Imports of agricultural and competitive manufactures decline at their maximum allowable rates. Aggregate real imports grow at an average rate of 1.3 percent annually and nominal imports at 5.4 percent annually. Even though foreign exchange is increasingly scarce, Egypt cannot afford to reduce imports of essential raw

materials and machinery in which the economy is non-competitive. In terms of spending, non-competing imports increase to more than three-fourths of the total by 2002.

A set of relative prices is presented in Table 5 where the prices are expressed relative to a consumer price index.[8] The original normalization rule sets all prices to unity in the base year, so that relative prices for that year are all one. Examination of the structure of the subsequent endogenously determined relative prices reveals that there is a very significant shift in the relative price structure that occurs in the model's initial period and is carried forward through the planning horizon. Reflecting the relative scarcities in the model and the underlying production costs in each sector, these shifts indicate that, if prices were set according to economic efficiency considerations and eliminating distortions, the price of foreign exchange and the price of energy would rise relative to other goods and services.

Table 5 shows the sharp increases in the relative prices of crude oil, petroleum products, and electricity. The prices of

8Since in the model itself the shadow prices, or marginal values of each good and its production costs, are measured in the same units as the utility function, for presentation purposes it is necessary to normalize them into a more readily comprehensible form. This is done by expressing the shadow prices for each year in terms of the consumer price index for that year. Specifically, we calculate the consumer price index for each year as the total cost, in terms of the units of the maximand, of purchasing one unit of private consumption in that year. The proportions or shares that each particular good represents in this index are the actual proportions for the base year (as shown in Table 3). Once this index is computed, the shadow prices for each individual good are calculated as the ratio of the shadow price for that good (in the units of the maximand) to the consumer price index for that year.

crude oil and refined products increase because of the intrinsic value of the foreign exchange generated by oil exports and because oil production is severely limited by the availability of reserves. The relative price of electricity increases to reflect the very large underlying capital costs of expanding generation capacity. At the same time, the relative price of natural gas declines because of the large growth potential in this sector, relative to reserves, low production costs, and the fact that it is a non-tradable item which can be used only for domestic purposes. The low relative shadow price of natural gas in the solution is consistent with the large scale substitution of natural gas for other energy products. The relative prices generated by the model provide further evidence of the large current energy price distortions in the Egyptian economy.

With the exception of transportation services, which turns out to have a relative price about equal to the consumer price index, the prices for non-energy goods and services decline somewhat in comparison with the consumer price index. This reflects underlying production costs and acts in the model to encourage production in these sectors.

GDP growth is the aggregate of growth in individual sectors. The time paths of gross output of the different sectors and the distribution of that output among the various technological alternatives are presented in Table 6. Production in agriculture, manufacturing and the natural gas sectors grow at a faster rate than the economy-wide average. Crude oil, petroleum products, electricity, and transport grow slower than average.

This scenario assumes that the total agricultural labor force increases at only 1.5 percent annually, while demand for domestic agricultural output increases more rapidly. Consequently agriculture gradually moves toward more capital-intensive techniques as is evident from the shift in production shares from technology 1 to technology 5 due to relative tightness in the labor supply. Investment in manufacturing is concentrated in the tecnology that is the least capital and energy intensive and most labor intensive. This saves on the required imports of equipment and as well reduces requirements. This shift in the composition of the manufacturing sector is gradual, because the model determines that it is economic to continue utilizing the existing capital and energy intensive production capacity while it slowly depreciates. Similar, gradual shifts in the technology pattern of production occur in the other sectors where it is economic to invest only in new technologies.

There is a marked increase in the share of investment directed to the agricultural sector. This is directly related to the shift of production methods towards capital-intensive and labor-saving technology in this sector, which frees labor for other sectors. The reduction in the share of investment occurring in manufacturing is due to the substitution of labor-intensive technologies for relatively capital-intensive methods of production. The lower shares for energy and transportation reflect slower growth in these sectors than occurred in the past,

when foreign exchange was more plentiful and the economy operated under highly distorted relative prices.

The energy supply and demand balances for crude oil, natural gas, petroleum products, and electricity in their own natural units are shown in Tables 7 to 10.

Production of crude oil declines over time because the assumed rate of new discoveries of reserves is less than the rate of production. Nonetheless, throughout the planning period exploitation of oil reserves occurs at the maximum technological limit of 7.5 percent of reserves each year in order to satisfy domestic demands and generate needed foreign exchange. After 1992, an increasing proportion of production is for input to domestic refineries. The solution shows a slight increase in near term exports as total production rises to its technical limits and because refinery demand is reduced. Substitution of natural gas for petroleum products takes place in the economy because natural gas is not as scarce as the other energy inputs. The observed decline in production, from 44 million tons in 1987 to 28.9 million tons in 2002, is due to the assumption that the annual rate of discoveries is only 20.5 million tons.

As indicated in Table 8, the model chooses to increase natural gas use, which grows at an average rate of more than 6 percent annually. Because there are no exogenous restrictions on the speed of substitution, there is very quick substitution (of refined products by natural gas) by 1992 in electricity and manufacturing. Afterwards, gas use increases at about 3 percent

annually. Nonetheless, throughout the planning period, production is demand constrained and never reaches its technical limits relative to reserves. Table 9 demonstrates the important implications for the petroleum sector of increased use of natural gas. Table 10 also illustrates the importance for electricity demand of technology choice in manufacturing.

It is also evident that higher prices for energy lead to a significant reduction in the energy-GDP linkage. This occurs through: (a) investment in energy-saving technologies in manufacturing, (b) changes in the sectoral composition of output, including reduced investment in transportation, and (c) slow growth of total consumer spending and consumers' reactions to higher energy prices.

V. SCENARIO ANALYSIS

An examination of alternative scenarios helps illustrate the model's potential and, as well, the implications of alternative assumptions and the constraints of the model. While not pretending to be definitive, the alternative scenarios help to exemplify the consequences of alternative energy and economic policies in the Egyptian economy.

The first scenario was intentionally constructed to be quite pessimistic and could be called the "worst case" scenario. It illustrates the potential consequences for the economy of many adverse circumstances occurring simultaneously, in the energy sector and on the international scene. The second scenario investigates the potential impact of relying only on reforms in the

energy sector to alleviate the economic problems associated with the "worst case". The focus of the third scenario is on the effects of macroeconomic and non-energy sector policy reforms to offset the negative effects of the first scenario. The fourth scenario combines energy and non-energy policies in a comprehensive package to deal with the negative implications of the first scenario. Charts 1 and 2 present a comparison of the results of the four different scenarios with the Base Case values for the period 2001/02. The height of the bars represent the percentage of base case values.

In the first, worst case, scenario it is assumed that world oil price falls to $9.5 per barrel in 1986/87 prices in 1992 and remains at that level through 2012. Oil and gas reserves discovered in each period are, pessimistically, reduced to one-half the amount in the Base Case. The maximum growth rate of manufactured exports is reduced to 2 percent annually. Foreign borrowing is reduced by 5 percent per year and international transfers and worker remittances are projected to grow at only one-half the rate of world inflation.

The macroeconomic results corresponding to this scenario are a sharp decline in levels and growth rates of GDP, overall there is an annual average rate of decline of 4.6 percent for the entire planning period. The model adjusts to the adverse circumstances by depressing consumption growth in the initial period to generate investible surplus to make the necessary adjustments to the adversity and provide for growth in the later periods.

In this solution the relative price of foreign exchange is substantially higher than in the Base Case, reflecting its increased scarcity due to the assumed fall in the world price of oil, more limited oil and natural gas reserves and reduced remittances. Exports are actually increased, at a slow rate of .85 percent, despite the economy wide adverse circumstances, to offset reductions in other sources of foreign exchange.

Imports are, of course, considerably reduced, due to the lack of foreign exchange earnings. This fall in imports is mainly in non-competitive imports, hence it implies a sacrifice in the real growth rate of the Egyptian economy. Because of the non-availability of foreign exchange Egypt would have to cut down its imports of essential raw materials and machinery. This is reflected in the marked fall in real investment in absolute terms from the 12141 LE in 1992 in the Base Case to only 17 percent of the Base Case level in this scenario. This fall in investment is the result of the very limited foreign exchange which reduces the availability of non-competing imports on which manufacturing and construction, the two major suppliers of investment goods are highly dependent.

The absolute level of aggregate private consumption is reduced dramatically in this worse case scenario to a level of 46 percent of the Base Case level in the year 2002. The intertemporal time path of consumption reveals a severe decline in the level of consumption in the initial period by an average annual rate of -5.8 percent in 1992. Then it declines by a modest an-

nual average rate of -.6 percent in 1997, following which we observe a small increase in the level of consumption by 2002.

The energy sector "reforms" implemented in the second scenario are: (1) the substitution of natural gas for petroleum products is not exogenously constrained; (2) oil exploration is assumed to be able to increase discoveries to a level equal to three-fourths that in the Base Case; (3) co-generation is permitted to produce as much as 30 percent of electricity used in manufacturing; (4) transmission and distribution losses are assumed to be reduced by 40 percent in the electricity grid.

Average annual macroeconomic growth is increased by almost 1.2 percent per year, compared to the "worst case" scenario and an average annual growth rate of .56 percent over the entire planning period is achieved. Nonetheless, the real level of GDP is still substantially lower than the Base Case. The rate of growth of private consumption as well as per capita consumption is also still much lower than in the Base Case. This is also true of the level of investment due to the relatively smaller amounts of foreign exchange available from exports and foreign financing, which limits the supply of the necessary non-competitive imports.

Rapid substitution of natural gas for petroleum products continue to take place in the manufacturing sector, thus releasing scarce crude oil resources for exports. Conservation and co-generation program succeed in reducing costs of electricity generation and also contribute to significant increases in oil ex-

ports in comparison with Scenario One, as is evident from Chart 2. This points to the important role of energy supply and conservation policies in significantly easing potential foreign exchange crises.

Scenario Three simulates the effects of macroeconomic and non-energy sector policy reforms: (1) improvements in organization and management in the public sector were assumed to lead to productivity gains of 1 percent annually in manufacturing and transportation sectors; (2) an export promotion policy for manufacturing products was assumed to succeed in raising the upper bound on growth of these exports to 11 percent; (3) direct foreign investment was assumed to grow to a level equal to one-third of remitted profits in Base Case.

In this case macroeconomic growth is increased by about 2.2 percent per year. Increased manufacturing exports and foreign investment allow significant increases in the level of non-competitive intermediate imports, leading to greater investment, consumption and overall economic growth. This illustrates again the important role of export and macroeconomic policy in reducing the real costs of stabilization programs.

Nonetheless average macroeconomic growth over the entire planning horizon still falls short of the Base Case scenario by 1.3 percent. This highlights the significance of energy recovery measures which had an important role in the preceding scenario but which are absent here. Crude oil exports fall dramatically in this scenario because an increase in domestic economic ac-

tivity leads to higher levels of demand for petroleum products, whereas constraints on the rate of growth of discoveries keep crude oil supply at a low level. Lack of interfuel substitution due to limited availability of natural gas also hurts exports from the crude oil sector.

Finally, in Scenario 4, all of the changes implemented in Scenarios 1, 2 and 3 are put in place. In terms of macroeconomic performance the combination of energy and macroeconomic policies succeeds in achieving an almost complete recovery from the "worst case" conditions of Scenario One to the conditions of the base case. These results are shown in Chart 1 and 2.

CONCLUSIONS

The following conclusions emerge from our study:

The model's solution indicate that the current relative prices of energy products as well as foreign exchange are rather distorted in the Egyptian economy. On grounds of economic efficiency (i.e. pricing energy at its real economic costs) the model indicates the desirability of a substantial upward adjustment in the domestic price of crude oil, petroleum products, electricity and foreign exchange.

The solutions also show the advantage of substitution away from the more valuable energy products to alternative domestic options such as increased use of natural gas, through gradual shifts in the technological pattern of industries. The solution shows that it is economic to increase domestic natural gas use which can not be exported but it is a good domestic substitute

for petroleum products and its reserves are plentiful compared to crude oil reseves .

Since foreign exchange is an extremely valuable resource, the solutions exploit the potential for export of non-energy products. Over time, the solutions utilize domestic and foreign exchange resources for structural adjustments so that the predominant role of energy exports can be replaced by non-energy exports and domestic production in the manufacturing, agriculture and services sector.

The solutions also embody changes in the sectoral composition of output by inducing faster rate of growth in agriculture, manufacturing and the natural gas sectors than the economy wide average. They also reduce the domestic demands for energy products like petroleum and electricity through intersectoral and interfactor substitution.

In addition to increased investment in energy saving technologies in the manufacturing sector, there is also a shift of production methods away from labor intensive to capital intensive technology in the agricultural sector. Consumers also respond to the increased price of energy by curtailing energy consumption.

The scenario analysis brings out certain basic features which sets the context for an analysis of policies. In the face of adverse macro-economic developments, in a petroleum exporting country such as Egypt with intensive domestic energy use, there is an important role for new energy supply and conservation policies. They can help significantly in easing a potential for-

eign exchange crisis and enhancing the contributions of macro-economic and trade policies in reducing the real costs of stabilization programs.

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Table 1

Endogenous Variables

B_t	Net foreign borrowing in year t
$C_{i,t}$	Private consumption of good i in year t
D_t	Foreign debt in year t
$E_{i,t}$	Exports of good i in year t
$I_{i,t}$	Investment demand for good i in year t
$I_{i,j,k,t}$	Demand for investment good i by sector j, technology k, in year t
$K_{i,k,t}$	Installed capacity in year t to produce good i using technology k
$\Delta K_{i,k,t}$	New capacity to produce good i using technology k,first available in year t
$M_{i,t}$	Imports of good i in year t
$P_{i,t}$	Shadow price of good i in year t
$R_{i,t}$	Reserves of hydrocarbon i (oil or natural gas) in year t
$U(C_t)$	Utility of per capita consumption in year t
W	Total discounted utility; the maximand
$X_{i,t}$	Gross domestic output of good i in year t
$X_{i,k,t}$	Gross output of good i, produced using technology k,in year t
$Z_{i,t}$	Intermediate deliveries of good i in year t

Table 2
Parameters and Exogenous Variables

a_i	Maximum annual rate of depletion of hydrocarbon resource i (oil or natural gas)
$a_{i,j,k}$	Input of good i per unit of production of good j using technology k
$a_{fuel,j,k}$	Input fuel per unit of production of good j using technology k
$a_{gas,j,k}$	Input of natural gas per unit of production of good j using technology k
$a_{pet,j,k}$	Input of petroleum products per unit of production of good j using technology k
$b_{i,j,k}$	Proportion of capital good i in the capital required to produce good i using technology k
$d_{i,k}$	Five-year rate of depreciation of capital for production of good i using technology k
e_i	Maximum rate of increase of exports of good i between two periods
i_t	interest rate of foreign debt in year t
g_i	Minimal post-terminal growth rate for sector i
$f_{i,k}$	capacity conversion factor for capitol producing good i using technology k
$ICOR_{i,k}$	Incremental capital-output ratio for production of good i using technology k
$l_{i,k}$	Demand for labor per unit of production of good i using technology k
$l_{agr,k}$	Demand for labor per unit of agricultural production using technology k
m_i	Maximum rate of fall of imports of good i between two periods
q_i	Conversion factor for hydrocarbon resource i (oil or natural gas)
$s_{j,k}$	Maximum share of natural gas in meeting fuel demand of producing good j using technology k
β_i	Elasticity parameter for consumption good i
γ_i	Intercept parameter for consumption good i
ρ	Utility discount rate between periods
$\overline{B}_t$	Maximum net foreign borrowing in year t
$\overline{G}_{i,t}$	Public consumption of good i in year t
I_{1987}	Aggregate imported in 1987
$\overline{L}_t$	Total supply of labor in year t
$\overline{L}_{agr,t}$	Supply of agricultural labor in year t
$\overline{N}_t$	Population in year t
$\overline{\Delta R}_{i,t+1}$	Discoveries of resource i (oil or natural gas) between year t and year t+1
$\overline{T}_t$	Other foreign exchange transfers in year t
$\overline{V}_t$	Foreign firms' profit remittances in year t
$\overline{W}_t$	Workers' remittances in year t
$p^e_{i,t}$	world price of exports at good i in year t
$p^m_{i,t}$	world price of imports at good i in year t

Table 4
Macroeconomic Variables, Constant Prices -- Base Case
(millions of 1986/87 LE, producers prices)

	1987	1992	1997	2002	avg. annual growth rate
Private Consumption	29001	31749	39678	46214	3.2%
Public Consumption	6327	7158	8099	9163	2.5%
Investment	8865	12141	12635	14426	3.3%
Exports	7559	8385	9538	11551	2.9%
Imports	10274	10581	11051	12526	1.3%
GDP	41023	48853	58899	68828	3.5%

Table 5
Relative Prices -- Base Case
(measured in terms of CPI)

	1987	1992	1997	2002	ave. annual growth rate
Agriculture	1.00	0.75	0.72	0.75	-1.9%
Crude Oil	1.00	3.30	3.64	3.10	7.8%
Natural Gas	1.00	0.52	0.65	0.67	-2.7%
Petroleum Products	1.00	2.45	2.81	2.65	6.7%
Electricity	1.00	2.02	3.11	3.73	9.2%
Manufacturing	1.00	0.68	0.71	0.71	-2.3%
Construction	1.00	0.83	0.85	0.84	-1.2%
Transport	1.00	1.05	1.05	1.07	0.4%
Services	1.00	0.77	0.61	0.68	-2.5%
Non-competing imports	1.00	2.40	2.65	2.25	5.6%
Foreign exchange	1.00	1.90	1.72	1.20	1.2%

Table 3

Ten Sector Transactions Matrix (Domestic Producer Prices), 1986/87

(units: mill. of pounds)

	Agri-culture	Crude Oil	Gas	Petro-leum	Elec-tricity	Man-ufacturing	Cons-truction	Transpor-tation	Ser-vices	Total Intermediate
1. Agriculture	3932	0	0	0	0	2749	0	4	122	6808
2. Crude Oil	0	0	0	1494	0	0	0	0	0	1494
3. Natural Gas	0	0	0	13	384	227	0	0	0	624
4. Petroleum	26	0	0	24	488	278	109	679	11	1616
5. Electricity	29	0	0	20	114	298	9	2	24	495
6. Manufacturing	732	30	4	161	46	6063	1588	258	608	9489
7. Construction	29	16	2	8	1	279	13	18	88	453
8. Transport	130	2	0	9	10	532	115	189	74	1061
9. Services	563	558	68	152	74	1789	382	587	1468	5640
10. Non-competing Imports	77	449	55	16	10	1913	582	140	135	3377
Intermediate Input Σ(1-10)	5518	1054	128	1897	1128	14126	2797	1877	2532	31057
Total Value Added	9594	1935	502	517	-342	9298	2090	3412	14026	41031
Gross Output	15112	2988	630	2413	787	23424	4887	5289	16558	

	Private Consumption	Government Consumption	Gross Investment	Stock Change	Exports	Imports	Final Demand	Total Demand
1. Agriculture	9574	349	0	95	140	1854	8305	15112
2. Crude Oil	0	0	0	-122	1616	0	1494	2988
3. Natural Gas	6	0	0	0	0	0	6	630
4. Petroleum	371	38	0	146	397	155	797	2413
5. Electricity	219	72	0	0	0	0	291	787
6. Manufacturing	11015	1394	1218	-569	1159	282	13935	23424
7. Construction	0	60	4374	0	0	0	4434	4887
8. Transport	1185	80	226	0	3167	430	4228	5289
9. Services	5772	4224	517	0	1080	676	10918	16558
10. Non-Competing Imports	859	110	2530	0	0	6877	-3377	0
Final Demand Σ(1-10)	29002	6328	8865	-450	7560	10273	41031	

Table 6
Sectoral Gross Output -- Base Case
(millions of 1986/87 LE)

	1987	1992	1997	2002	ave. annual growth rate
Agriculture, Tech 1	15112	13233	10240	7923	
Agriculture, Tech 4	0	4972	3847	2977	
Agriculture, Tech 5	0	0	8941	16550	
Agriculture, Total	15112	18206	23028	27451	4.1%
Crude Oil	2988	2613	2228	1965	-2.8%
Natural Gas	630	1223	1403	1643	6.6%
Petroleum Products	2413	1577	1719	1667	-2.4%
Electricity, Tech 1	787	676	580	498	
Electricity, Tech 2	0	120	292	479	
Electricity, Total	787	796	873	977	1.5%
Manufacturing, Tech 1	23424	16296	11337	7887	
Manufacturing, Tech 5	0	14223	25057	36766	
Manufacturing, Total	23424	30519	36394	44652	4.4%
Construction	4887	7223	7484	8756	4.0%
Transport, Tech 1	5289	5550	6117	6992	
Transport, Total	5289	5550	6117	6992	1.9%
Services	16558	18621	23609	26805	3.3%

Table 7
Supply and Demand of Crude Oil -- Base Case
(millions of tons per year)

	1987	1992	1997	2002	ave. annual growth rate
Production	44.0	38.5	32.8	28.9	-2.8%
Exports	23.8	24.1	17.1	13.7	-3.6%
Refinery Input	22.0	14.4	15.7	15.2	-2.4%

Table 8
Supply and Demand of Natural Gas -- Base Case
(billions of cubic feet per year)

	1987	1992	1997	2002	ave. annual growth rate
Production	222.8	428.3	491.3	575.3	6.5%
Electricity	134.5	256.5	293.9	340.9	6.4%
Manufacturing	82.0	150.8	176.1	213.2	6.6%
Other users	6.3	21.0	21.3	21.2	8.4%

Table 9
Supply and Demand of Petroleum Products -- Base Case
(millions of tons per year)

	1987	1992	1997	2002	ave. annual growth rate
Production, net	20.3	13.3	14.5	14.1	-2.4%
Imports	1.3	0.3	0.1	2.1	3.3%
Electricity	4.2	1.3	1.1	0.9	-9.4%
Agriculture	0.3	0.3	0.4	0.5	4.1%
Manufacturing	2.4	1.8	2.1	2.5	0.4%
Construction	0.9	1.4	1.4	1.6	4.0%
Transport	5.8	6.0	6.7	7.6	1.9%
Services	0.1	0.2	0.2	0.2	3.3%
Consumption	3.2	2.3	2.3	2.3	-2.0%
Government	0.3	0.4	0.4	0.5	2.5%
Domestic demand	17.1	13.6	14.6	16.2	-0.3%
Exports	3.4	0.0	0.0	0.0	NA

Table 10
Supply and Demand of Electricity -- Base Case
(millions of KWH per year)

	1987	1992	1997	2002	ave. annual growth rate
Generation, gross	33354	33721	36991	41425	1.5%
Grid losses	4836	4890	5364	6007	1.5%
Net generation	28517	28832	31627	35418	1.5%
Agriculture	1281	1754	2873	3856	7.6%
Manufacturing	12905	13800	14742	16810	1.8%
Construction	414	612	634	742	4.0%
Services	702	789	1001	1136	3.3%
Energy sectors	818	535	583	565	-2.4%
Consumption	9281	7889	7889	7889	-1.1%
Government	3051	3452	3906	4419	2.5%
Domestic demand	28453	28832	31627	35418	1.5%

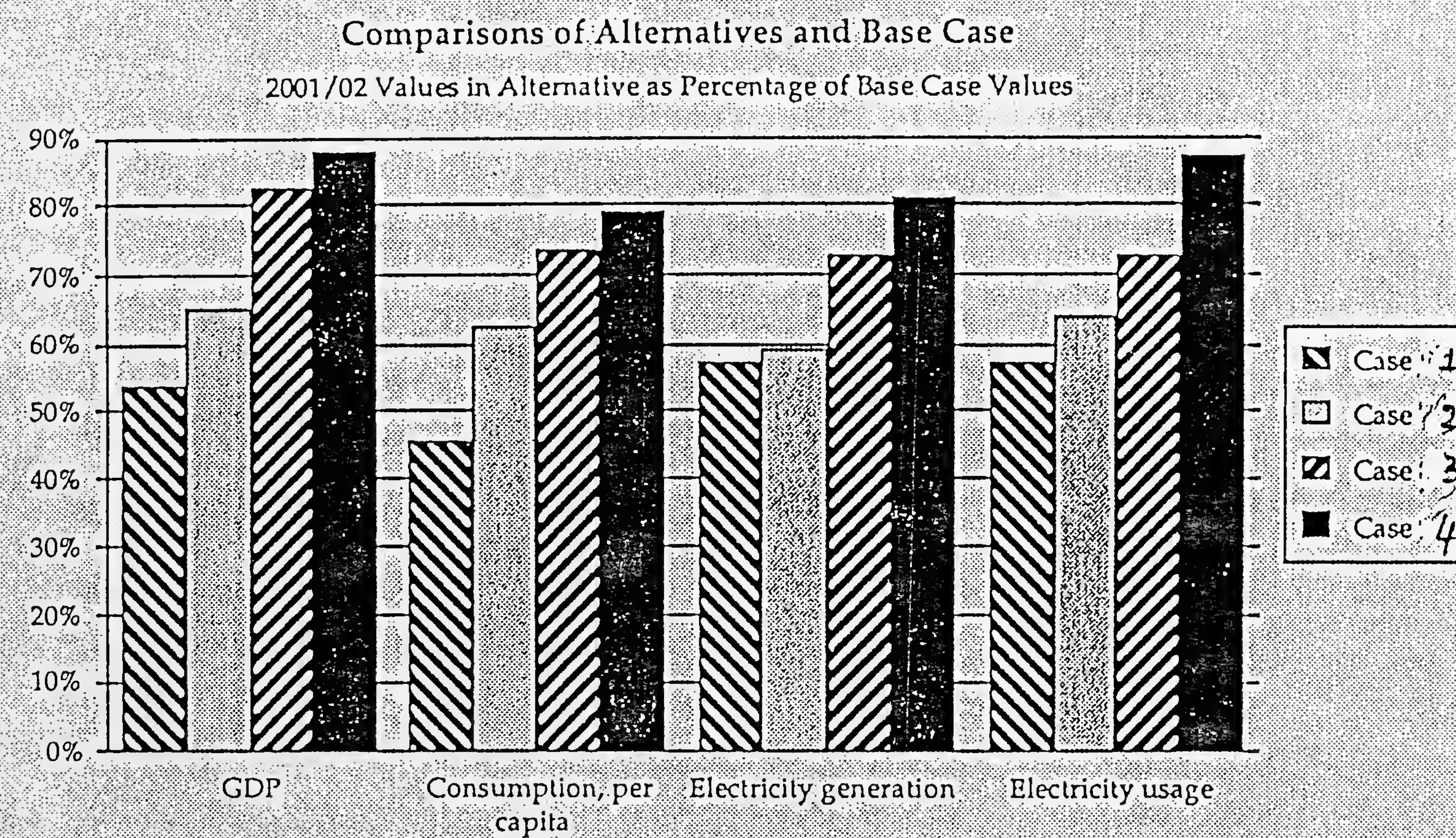
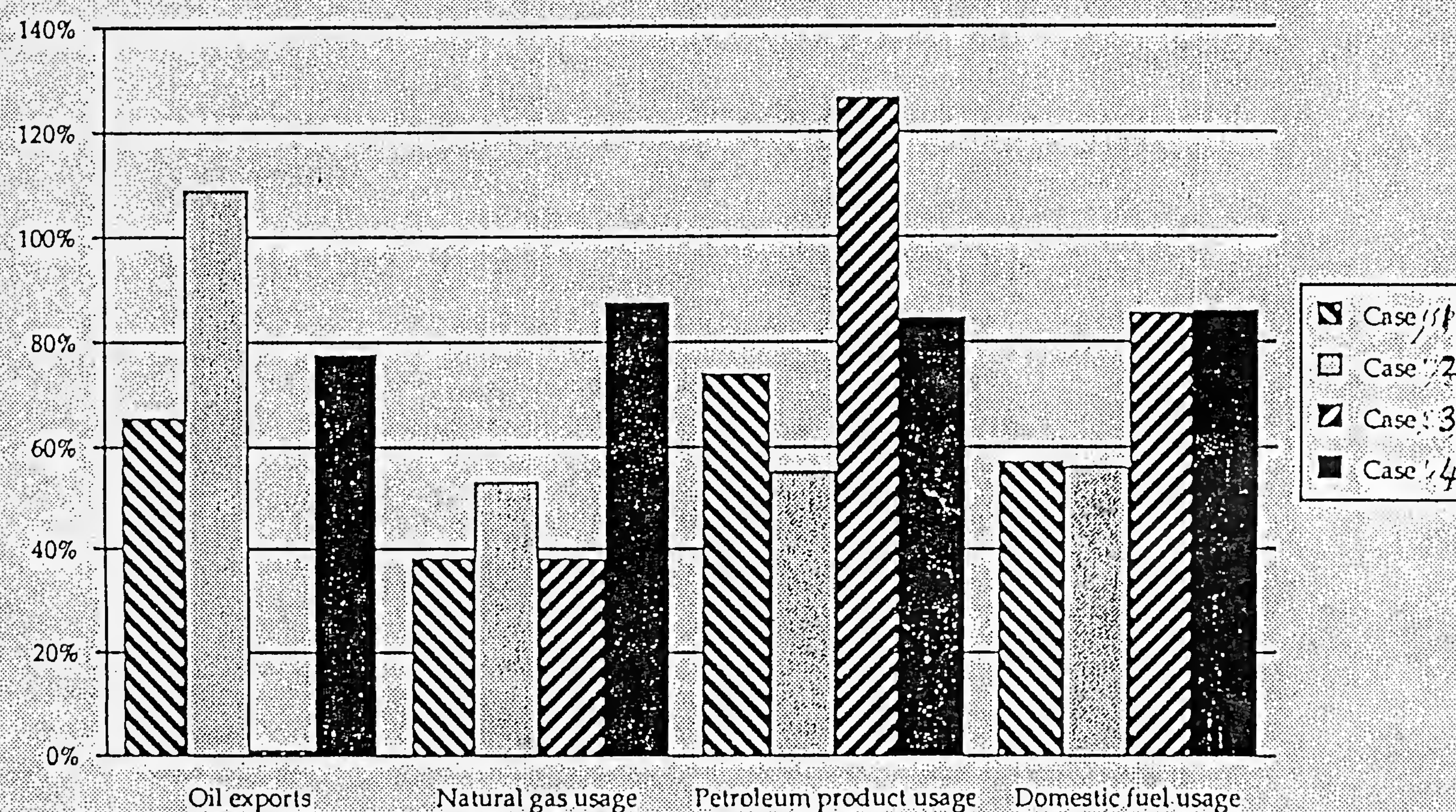

Comparisons of Alternatives and Base Case
2001/02 Values in Alternative as Percentage of Base Case Values
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
GDP
Consumption, per capita
Electricity generation
Electricity usage
Case 1
Case 2
Case 3
Case 4

CHART 2

Comparisons of Alternatives and Base Case

2001/02 Values in Alternative as Percentage of Base Case Values



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